Laboratory Determination of the Thermal Conductivity of a Typical Nigerian Granite Rock.

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ABSTRACT

This paper investigates the thermal conductivity of granite in view of its availability and usage in building and construction. The thermal conductivities of discs made from cement bonded granite chippings were determined. The discs had the same diameter but with varied thickness and were also compressed under different pressures. The values of the thermal conductivity were between 0.18 and 0.43 $Wm^{-1}K^{-1}$. It shows that granite is a poor conductor of heat and a correlation coefficient of 0.78 exists between the compression pressure and the thermal conductivity. This indicates that porous granite of low density will be a suitable thermal insulator when used as aggregates in walls and roof tiles.

(Keywords: thermal conductivity, pressure, granite, Lee's disc)

INTRODUCTION

Thermal conductivity describes how easily heat can be transported through a material. It depends on the state of the material, which is a function of the chemical composition and physical structure. A low thermal conductivity indicates a heat insulating material.

Granite is a common type of intrusive igneous rock. Its color is usually white or black/buff, but depending on the mineralogy, it can occur as pink or dark grey (Lutgens and Tarbuck, 2000). It has found application in many areas of the construction industry, such as, the making of door lintels, jambs, wall veneer and as floor tiles in public buildings and monuments. It is not easily deformed by heat, and is durable and resistant to weathering.

The conduction of heat through walls determines to a large extent, the interior temperature of buildings. Temperature control through the use of mechanical devices is being utilized. However, due to the cost of electricity and the effect of greenhouse gases produced during the generation of electricity, the need to passively cool the interior of buildings has become of interest (Ekpe and Akpabio, 1994). Hence, interest in the determination of the thermal conductivity of granite.

In their work on the measurement of thermal conductivity of Earth materials, Horai and Simons (1969) pulverized the specimen into fine powder, mixed it with distilled water and used the needle-probe technique. The conductivity of the solid specimen was then deduced from the conductivity of the mixture by an empirical relationship. In another method the sample was crushed into small fragments, saturated with water and confined in a water-tight container. The thermal conductivity was measured by the divided-bar technique and an empirical relationship was used to determine the conductivity of the solid rock.

The present study makes use of the Lee's disc apparatus to determine the thermal conductivity of compressed, cement bonded granite chippings. The compression pressure was also varied to simulate changes in the density of granite and the effect on the thermal conductivity was measured.

MATERIALS AND METHODS

The granite chippings obtained from a quarry at Ogbere, Ogun State, Nigeria, were sieved through a 0.3mm mesh and 1.6 Kg of chippings was mixed with 0.5 Kg of cement with water added to good consistency.

The mixture was poured into a compression molder having a diameter of 11cm and extruded at predetermined pressures with the use of a 10 ton hydraulic jack. Samples were cut with a guillotine and left to dry in the sun. These were later placed in an oven at 105°C for several hours to ensure complete dryness.

The thermal conductivity of each sample was determined in the Lee's disc apparatus through a known procedure (Nelkon and Parker, 1978).

RESULTS AND DISCUSSION

The thermal conductivity k, of the sample is given by:

$$k = \frac{mcl}{A(\theta_2 - \theta_1)} \frac{d\theta}{dt} \quad \textbf{(1)}$$

m is the mass of the lower plate in the Lee's disc apparatus, c is its specific heat capacity, l is the thickness of the sample, A is the area of the sample, θ_1 and θ_2 are the respective steady state temperatures of the upper and lower plates and $\frac{d\theta}{dt}$ is the rate of cooling of the lower plate at steady state.

The parameters of the samples and the measurements are listed in Table 1.

An ingenious method was employed in the determination of $\frac{d\theta}{dt}$. This was done to eliminate the error that could arise when drawing tangent to a curve.

Figure 1 shows the cooling curve of the lower plate for sample 1 in which the data points were fitted by a function. Suppose:

$$\theta = f(t) \quad \textbf{(2)}$$

$$\frac{d\theta}{dt} = f'(t) \quad \textbf{(3)}$$

At steady state, $\theta = \theta_2$:

$$\theta_2 = f(t_2) \quad \textbf{(4)}$$

Conversely,

$$t_2 = f^{-1}(\theta_2) \quad \textbf{(5)}$$

Therefore,

$$\left.\frac{d\theta}{dt}\right|_{\theta = \theta_2} = f'(t)\big|_{t = t_2 = f^{-1}(\theta_2)} \quad \textbf{(6)}$$

All the data in this work were fitted by exponential functions of the form:

$$\theta = a\exp^{-bt} \quad \textbf{(7)}$$

a and b are the curve fitting parameters. We then have that:

$$f'(t_2) = -ab\exp^{-\ln\left(\frac{a}{\theta_2}\right)} \quad \textbf{(8)}$$

$$k = \frac{mclab}{A(\theta_1 - \theta_2)}\exp^{-\left(\frac{a}{\theta_2}\right)} \quad \textbf{(9)}$$

The correlation coefficient between the compression pressure and the measured thermal conductivity was also calculated to be 0.78.

The negative effects of global warming have elicited interest in ways to reduce the generation of greenhouse gases. A major source of greenhouse gases occurs during electricity generation as a result of the burning of fossil fuels. If electric power consumption is reduced, then global warming could be minimized.

A significant amount of electric energy is consumed in the control of indoor temperature, either by cooling or heating. The indoor temperature is markedly affected by the transmission of heat through walls and roofs. Therefore, the use of low thermal conductivity materials for roofs and walls would be environmentally friendly.

Table 1: Sample Parameters and Measured Values.

Mass of lower disc (Kg)								1.50
Specific heat capacity of lower disc ($JKg^{-1}K^{-1}$)								370
Cross sectional area of lower disc (m^2)								3.01×10^{-3}
Sample Number	**Comp. Pressure (bar)**	**Curve fitting parameters**		**Sample Thickness ($\times 10^{-3}$ m)**	**Plate Temp. (°C)**		**Thermal Conductivity ($Wm^{-1}K^{-1}$)**	
		a	**b**		θ_1	θ_2		
1	4	48.47	0.0005	9.8	90	37	0.198	
2	7	58.64	0.0004	7.3	95	49	0.180	
3	8	55.69	0.0004	12.0	95	46	0.261	
4	10	56.60	0.0004	10.8	95	47	0.245	
5	12	54.12	0.0005	13.6	90	47	0.431	
6	14	56.30	0.0005	11.7	96	51	0.299	
7	15	56.40	0.0004	12.1	90	46	0.379	

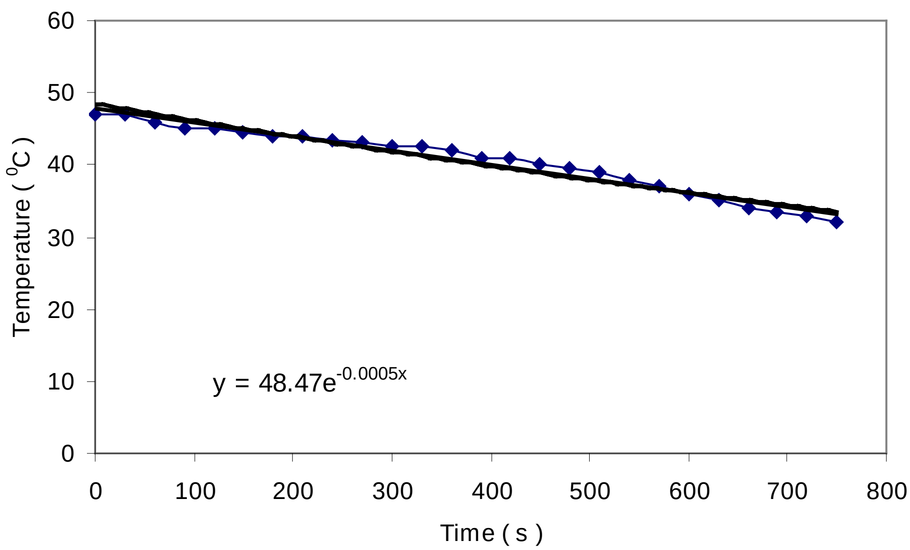

Figure 1: The Cooling Curve for Sample 1.

Thermal conductivity values ranging from 0.18 to 0.43 $Wm^{-1}K^{-1}$ were obtained for compression pressures between 4 and 15 bars and a correlation coefficient of 0.78 exists, indicating that low density granite will have a low thermal conductivity. The measured thermal conductivities are in agreement with values obtained by other methods (Woodside and Messmer, 1961).

Porous granite of low density could be artificially produced by blowing gas through molten rock (similar to the natural production of pumice) and by the making of granite micro beads. However, the mechanical strength of structures derived from any low density granite would need to be ascertained.

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